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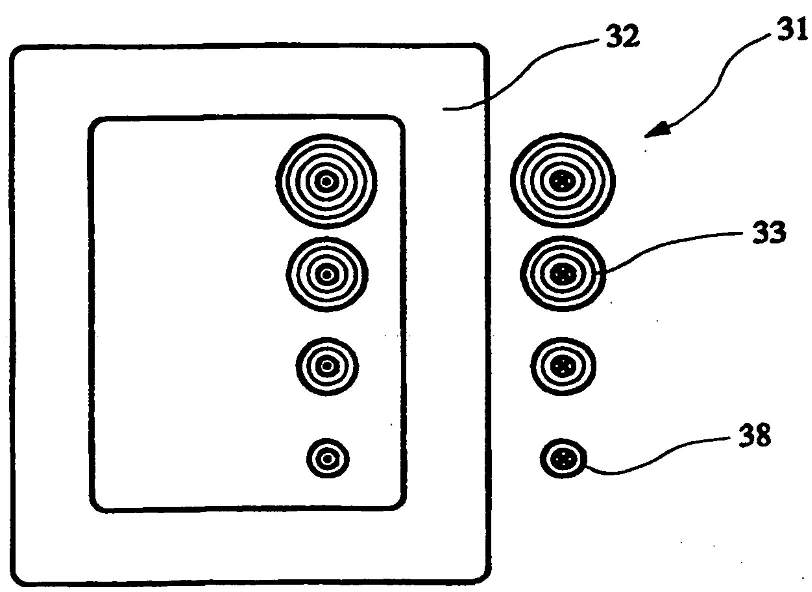
(54) Title: WINDING IN TRANSFORMER OR INDUCTOR

(57) Abstract

A power transformer or inductor is disclosed. The winding (31) of the transformer/inductor is made of a flexible conductor (38) having electric field containing means forcing the electric field due to the electric current in the winding (31) to be contained within the insulating layer of the flexible conductor (38). The thickness of the insulating layer of the flexible conductor (38) is adopted in such a way to make the electric stress (33) constant throughout the length of the winding. The cross section area of the insulating layer of the flexible conductor (38) is thus optimized, providing for a transformer/inductor design with a high space factor.



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Winding in transformer or inductor

TECHNICAL FIELD

The present invention relates to power transformers or inductors in a power generation, transmission or distribution system with a rated power ranging from a few hundred kVA up to more than 1000 MVA and with a rated voltage ranging from 3-4 kV and up to very high transmission voltages, 400 kV to 800 kV or higher. More specifically the invention relates to the winding of power transformers or inductors.

BACKGROUND OF THE INVENTION

In power transformer/inductor design the space factor of a winding, that is the ratio between the volume occupied by the conductor in the winding and the total volume of the winding, is an important parameter. Windings with high space factors are advantageous since they display a compact design and low leakage flux.

SUMMARY OF THE INVENTION

The objective of the present invention is to provide a power transformer or inductor comprising a flexible conductor having electric field containing means as well as inner electric field equalizing means, which presents a design which is technically favourable and allows a high space factor. The invention is made possible by the use of said flexible conductor in at least a part of the winding or windings in the power transformer/inductor.

An example of a flexible conductor having electric field containing means, is a flexible XLPE-cable of the sort used for power distribution. Such a cable comprises a conducting core, a first semiconducting layer provided around said conducting core, a solid insulation layer provided around said first semiconducting layer and a second semiconducting layer provided around said insulation layer. On the condition that the second semiconducting layer is grounded the cable has the ability to, within itself, contain the electric field arising from the current in the conducting core. The electric stress is thus absorbed within the solid insulation of the cable and there is virtually no electric field outside the second semiconducting layer. In a XLPE-cable the different layers are firmly attached to each other. Also, the solid insulation layer and the semiconducting layers are made of materials which have almost the same coefficient of expansion. The cable can therefore be subjected to mechanical and thermal stress without the layers separating from each other, forming cavities in-between the layers. This is an important feature, since partial discharges will appear in a cavity if the electric field stress exceeds the dielectric strength of the gas in the cavity. It is especially important that the first semiconducting layer and the solid insulation layer is firmly attached to each other since the electric field stress is largest in this part of the cable. A splitting up in this region will allow air in the division between the layers and thus lead to partial discharges. A cable similar to the sort presented above is described in PCT applications WO-97/45847 and WO-97/45921.

It is known that the voltage in a power transformer or inductor is unevenly distributed over the turns of a winding. For example, for a single-phase power transformer or inductor where the winding is grounded in one end and connected to a line terminal in the other, the part of the windings connected to ground will have an electric potential close to zero. On the other hand, the part of the winding connected to the line terminal will have a maximum electric potential close to the phase voltage. The line side of the winding is therefore subjected to higher insulation loads than the ground side. To prevent flash-overs between the winding and details close to the winding, e.g. the core or the casing surrounding the power transformer or inductor, a better electric insulation is required on the line side than on the ground side. The required electric insulation thus changes along the length of the winding. For a three-phase system there are two basic ways to connect the windings of the phases, star connection (Y) and delta connection (Δ). The connections Y or Δ can be arbitrarily chosen for the high voltage and the low voltage side of the transformer. In the Y connection one

winding end of each phase is connected together, forming a neutral terminal. If the neutral terminal is grounded, the part of the windings connected to the neutral will have an electric potential close to zero and the part of the windings connected to the line terminals will have a maximum electric potential close to $U_L/\sqrt{3}$, where U_L is the line-to-line voltage. The situation is thus similar to the single-phase example above in that the required electric insulation changes along the length of the windings. In the Δ connected system the windings of all phases together form a closed loop, a delta, and the line terminals are connected to the three corners of the delta. If the system is symmetric, the electric potential in the middle of each winding will be close to zero. On the other hand, the maximum electric potential at the end of each winding will be $U_L/2$. Once again the insulation load changes along the length of the windings and so does the required electric insulation.

In a power transformer or inductor where at least some part of the winding is formed by a cable, it is possible to adopt the thickness of the cable insulation to the actual insulation load along the windings. By using such a tapered flexible conductor in the windings a number of advantages are obtained. The space factor of each winding can be increased since non-required cable insulation can be removed. Therefore, it is possible, for a given capacity rating, to make the windings smaller and thus the whole transformer/inductor will be smaller and cheaper to manufacture. Reduced winding thickness and thus reduced mean distance between the conductor and the core will also result in reduced leakage flux and thus reduced impedance of the transformer/conductor. Alternatively, keeping the space factor unchanged, the cooling will be more efficient since the cooling medium will be able to circulate more easily in the transformer/inductor when the cable insulation is reduced. Since cooling is often the limiting factor in power transformer/inductor design, the capacity rating of a transformer/inductor of a given size can be increased.

Ideally, the thickness of the insulating layer of the cable should be such that the electric stress in the cable, in principal, is the same throughout every turn of the winding. This requires the cross section area of the insulating layer to vary along the length of the cable. The cross section area may vary continuously or step-wise in one or more steps. A cable with a step-wise varying insulation cross section area may be made of cable parts with different but uniform insulation cross section areas that are joined together. The insulation cross section area may

decrease along the length of the cable, the cable then having its smallest insulation cross section in one end of the winding. The cable may alternatively have its smallest insulation cross section area in the middle of the winding, as is suitable for a winding in a Δ-connection, or at any other position, all according to how the insulation load changes along the winding.

BRIEF DESCRIPTION OF THE DRAWINGS

With reference to the enclosed drawings, a detailed description and different preferred embodiments of the invention will be described hereinafter.

Fig. 1 is a simplified view showing the electric field distribution around a winding of a conventional power transformer or inductor.

Fig. 2 is a simplified view showing the electric field distribution around a winding of a power transformer or inductor of the sort described in PCT applications WO-97/45847 and WO-97/45921.

Fig. 3 is a simplified view showing the electric field distribution around a winding of a power transformer or inductor according to a first preferred embodiment of the invention.

Fig. 4 is a simplified view showing the electric field distribution around a winding of a power transformer or inductor according to a second preferred embodiment of the invention

Fig. 5 is a simplified side view showing two examples of step-wise tapered cables and two examples of continuously tapered cables used in windings in a power transformer or inductor according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

The figures 1-3 referred to in the text below are simplified and fundamental views. The figures can represent a inductor, with or without a core, as well as a

power transformer. For simplicity reasons, only one winding is shown in each figure. Also for simplicity reasons, windings with only one layer and only four turns are shown in the figures, however, the reasoning below holds for windings with many layers and a multitude of turns.

Figure 1 shows a simplified view of the electric field distribution around a winding of a conventional power transformer or inductor with a winding 11 and a core 12. Around each turn of the winding 11 there are equipotential lines 13, that is, lines where the electric field has constant magnitude. The lower part of the winding is assumed to be at ground potential and the upper part is assumed to be connected to a line terminal. The potential distribution determines the composition of the insulation system since it is necessary to have sufficient insulation both between adjacent turns of the winding and between turns of the winding and grounded details surrounding the winding. The equipotential lines 13 in the figure shows that the upper part of the winding is subjected to the highest insulation loads.

Figure 2 shows a simplified view of the electric field distribution around a winding of a power transformer or inductor described in PCT applications WO-97/45847 and WO-97/45921. A winding 21 made up by a cable 28 wound round a core 22. In the cable 28 equipotential lines 23 are shown. The cable 28 comprises a conducting core 24 surrounded by a first semiconducting layer 25, a solid insulation layer 26 of uniform thickness and a second semiconducting layer 27. The second semiconducting layer 27 is connected to ground potential. The lower part of the winding is assumed to be at ground potential and the upper part is assumed to be connected to a line terminal. The electric field arising from the current in the conducting core is enclosed in the cable 28 by the semiconducting layer 27 and there is no electric field outside the cable 28. The upper part of the winding is subjected to the highest insulation loads and the electric stress absorbed within the insulation layer of the cable in the upper part of the winding is larger than the stress absorbed in the lower part. This is indicated in the figure by the spacing between the equipotential lines 23 in the cable which are smaller in the upper part as compared to the lower part of the winding. The insulation layer in the cable is dimensioned to withstand the highest electrical stress in the winding, that is the stress in the upper part of the winding. This means that the insulating layer in the lower part of the winding is unnecessarily thick.

According to the invention, a favourable design of a power transformer or inductor comprising a cable is obtained by adapting the thickness of the insulation of the cable to the actual insulation loads along the winding. As an example, with reference to figure 2, it is thus possible to reduce the thickness of the insulating layer of the cable in the lower part of the cable winding 21. This is achieved by using a tapered cable in which the cross section of the insulating layer decreases towards the grounded side, that is the lower part, of the winding. Ideally, the insulation thickness should be such that the electric stress in the cable is, in principal, the same through out the length of the winding. The electric field distribution around a cable in such a winding is shown in figure 3 which shows a simplified view of a first preferred embodiment of the invention. In the figure, a cable 38 is wound round a core 32 forming a winding 31. In the cable 38 equipotential lines 33 are shown. As in figure 2 the lower part of the winding is assumed to be at ground potential and the upper part is assumed to be connected to a line terminal. The cross section area of the insulation layer of the cable in the winding changes continuously in such a way that the electric stress in the cable is, in principal, constant throughout the winding, as is indicated by the equipotential lines 33. As compared to the power transformer/inductor shown in figure 2, the cooling will be more efficient since the cooling medium will be able to circulate more easily in the transformer/inductor when the cable insulation is reduced.

In figure 4 a simplified view of a power transformer/inductor according to a second preferred embodiment of the invention is shown. Analogous to figures 2 and 3, a cable 48 is wound round a core 42 forming a winding 41. In the cable 48 equipotential lines 43 are shown. Once again the lower part of the winding is assumed to be at ground potential and the upper part is assumed to be connected to a line terminal. In figure 4 the turns of the tapered cable are stacked on top of each other. As compared to the windings in figures 2 and 3, the space factor of the winding is thus increased and the power transformer/inductor can be made smaller and thus cheaper.

Instead of using a cable with continuously varying insulation cross section area in the winding, the cross section area may change step-wise. By joining two or more cable parts with different but uniform insulation cross section areas, such a cable may be obtained. In figure 5, four cables, 50a, 50b, 50c and 50d that can be used in a power transformer/inductor according to the invention are shown. Cables 50a and 50b are made of three cable parts, 51a, 52a, 53a and 51b, 52b, 53b

respectively. In the splices 54a, 55a and 54b, 55b respectively, the conducting core 56a respectively 56b, the first semiconducting layer (not shown) and the second semiconducting layer (not shown) of neighbouring cable parts are connected. The cables 50c and 50d are each made of one cable part, the insulation cross section area of which changes continuously along the length of the cable. In cable 50a and 50c, the insulation cross section area increases along the length of the cable. Such a cable is suitable in a power transformer/inductor where the insulation stress steadily increases along the winding as is the case in, for example, a Y connected three-phase transformer where the neutral is grounded. In cable 50b and 50d the insulation cross section area is smallest on the middle. Such a cable is suitable in a Δ connected three-phase transformer where the insulation stresses are smallest half way through the windings. The number of cable parts in cables 50a and 50b does not have to be restricted to three. By using a plurality of cable parts of different lengths and insulation cross section areas, a cable with a more or less continuously varying insulation cross section area may be produced.

The winding arrangement described above teaches how to apply a tapered cable to a winding in order to bring about a power transformer or inductor according to the invention. It is understood, however, that it is possible to apply tapered cables to single- or polyphase transformers with one or a plurality of windings as well as to inductors, with or without cores, comprising one or a plurality of windings, without deviating from the scope of the invention. It is also understood that it is possible to, within the scope of the invention, apply a tapered cable to a power transformer/inductor where only a part of the winding consists of a cable.

CLAIMS

1. A power transformer or inductor in a power generation, transmission or distribution system comprising at least one winding (31, 41), characterized in that the winding at least partly is made up by a flexible conductor having electric field containing means (38, 48) and that the cross section area of said flexible conductor varies along at least a part of the length of said flexible conductor.

2. A power transformer or inductor according to claim 1, characterized in that the flexible conductor is made up by a cable (38, 48) comprising a conductor (24), a first layer (25) having semiconducting properties, a solid insulation layer (26) provided around said first layer and a second layer (27) having semiconducting properties provided around said solid insulating layer.

3. A power transformer or inductor according to claim 1 or 2, characterized in that said cross section area of the flexible conductor or cable (50c, 50d) varies continuously along at least a part of the length of said flexible conductor or cable.

4. A power transformer or inductor according to claim 1 or 2, characterized in that said cross section area of the flexible conductor or cable (50a, 50b) varies step-wise along at least a part of the length of said flexible conductor or cable.

5. A power transformer or inductor according to any of claims 1-4, characterized in that the electric stress in the flexible conductor or cable (38, 48) is in principal constant throughout the length of said flexible conductor or cable.

6. A power transformer according to any of claims 1-5, characterized in that the power transformer comprises three phases which are Y connected.

7. A power transformer according to any of claims 1-5, characterized in that the power transformer comprises three phases which are Δ connected.

8. A power transformer or inductor according to any of the claims 1-6, **characterized** in that one end of at least one winding is at ground potential.

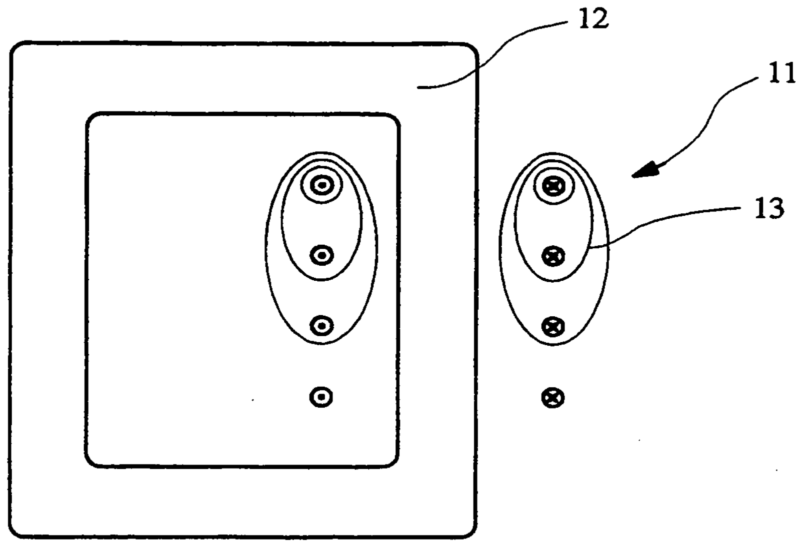

Fig. 1

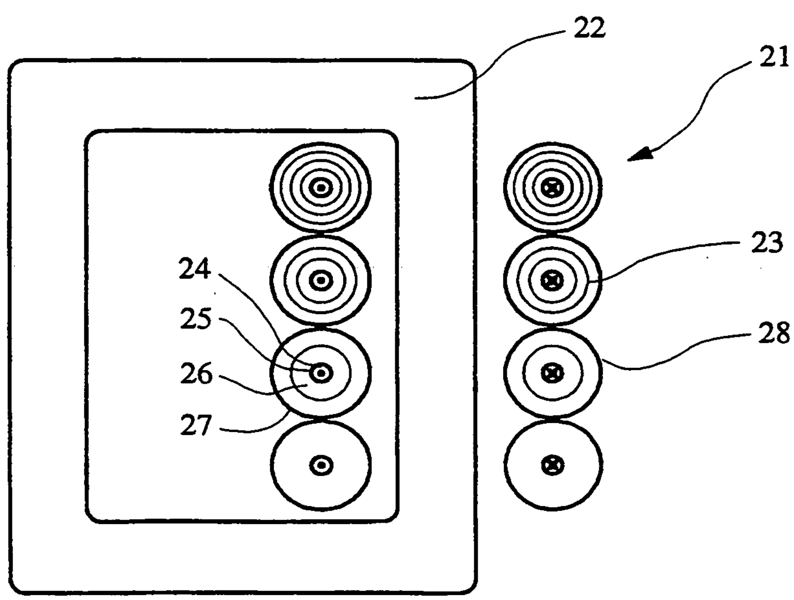

Fig. 2

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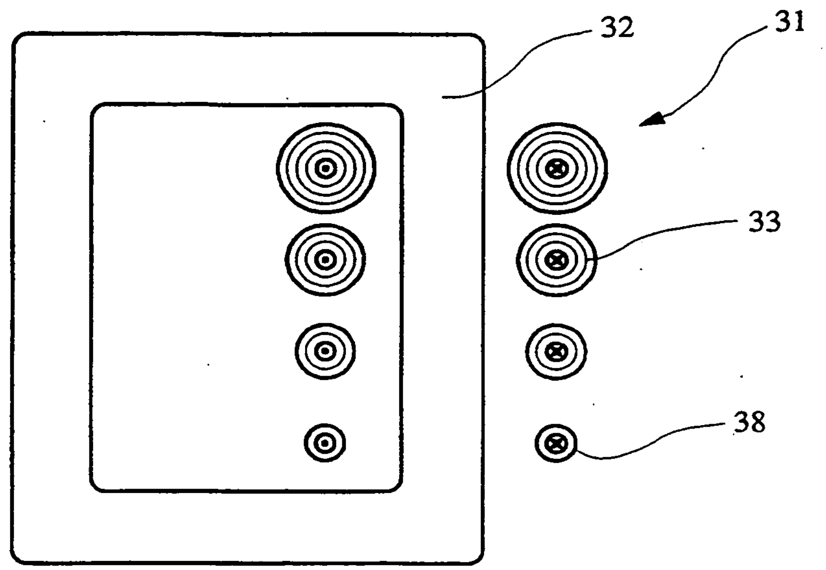

Fig. 3

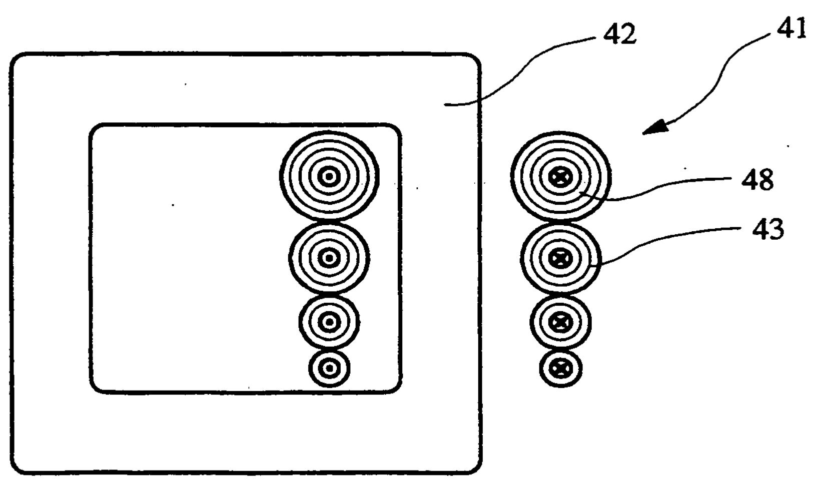

Fig. 4

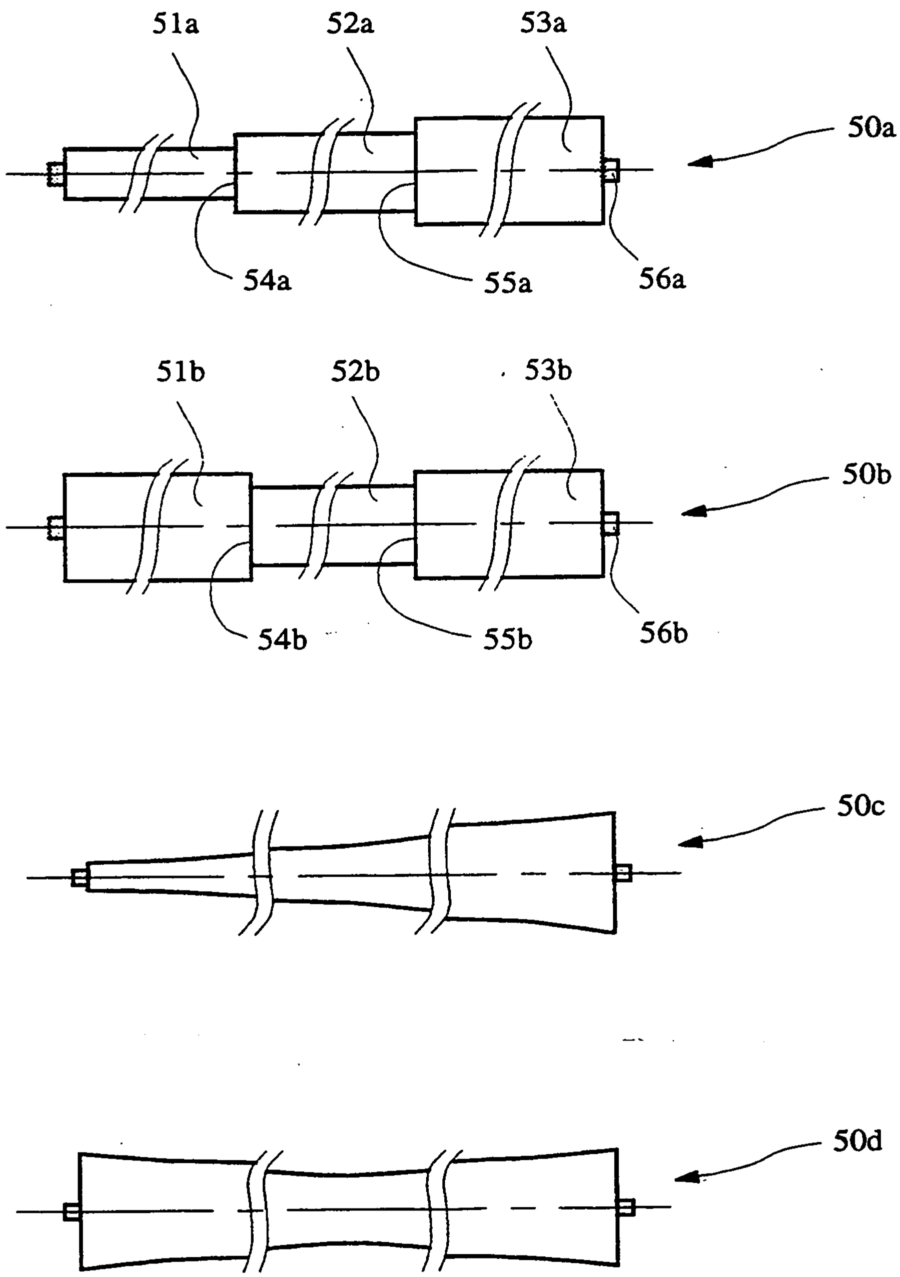

Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00152

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: H01F 27/32
According to International Patent Classification (IPC) or to both national classification and IPC

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IPC6: H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

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EDOC, WPIL, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5036165 A (RICHARD K. ELTON ET AL), 30 July 1991 (30.07.91), abstract --	1
A	Patent Abstracts of Japan, abstract of JP 4-24909 A (MITSUBISHI ELECTRIC CORP), 28 January 1992 (28.01.92) -- --------	1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

09/06/98

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US 5036165 A	30/07/91	US 5066881 A	19/11/91
		US 5067046 A	19/11/91
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		US 4853565 A	01/08/89